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**PIPE FABRICATION TO SUPPORT MODERN
SHIP CONSTRUCTION METHODOLOGY**

The Implementation of an Integrated Fabrication
Control Philosophy in a Modernized Shipyard Pipe Shop

16 August, 1985

David J. Saginaw II .
Staff Engineer, Piping

National Steel and Shipbuilding Company
Harbor Drive and 28th Street
San Diego, California 92138

Pipe Fabrication to Support Modern Ship Construction Methodology

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ABSTRACT

In October of 1983, National Steel and Shipbuilding Company, as part of a yard-wide advanced technology implementation program, initiated a project to modernize its existing pipe fabrication operation. The modernization included facility enhancements, equipment acquisitions and involved the implementation of an integrated manufacturing control philosophy beginning in design and employing principles of group technology with respect to pipe fabrication.

The paper summarizes the efforts associated with the pipe fabrication modernization project by tracing the facility enhancement from the initial feasibility studies to detailed shop layout and by describing the operating procedures currently being implemented in the pipe shop to support an integrated manufacturing control philosophy. An assessment of the favorable impact on productivity of the new facility and methodology is discussed as well as several facility and technology enhancements identified as appropriate steps to further improvement in pipe fabrication productivity.

1.0 INTRODUCTION

Maritime Industry Perspective

Worldwide, the shipbuilding industry is suffering from an imbalance in the supply and demand of most forms of sea-going tonnage. Current overcapacity conditions, as well as the present world economy have produced an extremely soft demand for new construction, conversion and repair projects. In this market environment, the ability to seriously compete for available work requires that shipyards maximize the quality of the product they produce while minimizing building cycles and total costs. While lower labor rates are a significant factor in minimizing costs, shipyards must adopt long-range strategies that incorporate more efficient, advanced ship construction methodologies. as employed by leading Japanese shipyards today.

Domestically, high labor rates and less technologically advanced construction techniques have made American shipyards non-competetive on a world-wide basis. Additionally, the elimination of construction differential subsidies has discouraged domestic operators from considering domestic yards for new building projects. The implementation of advanced ship construction technology in domestic shipyards is required for their commercial survival. In several yards, this implementation has begun, with favorable results reported thus far.

Background

In the spring of 1983 National Steel and Shipbuilding Company (NASSCO) initiated a yard-wide advanced technology implementation program encompassing all facets of ship construction including planning, materials procurement, engineering, information systems and production. Part of this implementation program involved the creation of several projects addressing key functions in the shipbuilding process identified as potential sources of productivity improvement. The projects, identified as "Group Technology Implementation Projects", were generally organized with a project leader who had the responsibility of and authority to change existing systems or procedures addressed in the specific project. Supplying research and technical support for the project was a staff assistant with consultation provided by one of several consultants from Ishikawajima-Harima Heavy Industries (IHI) Marine Technology Group.

Group Technology Implementation Project #11: "Pipe Shop Layout and Product Flow" was initiated in October of 1983.. The purpose of the project was to modernize the existing pipe fabrication operation at NASSCO through the application of facility enhancements and equipment acquisitions to increase the level of manufacturing technology in the shop and to provide an integrated manufacturing control philosophy beginning in design and incorporating all areas of pipe fabrication control.

This paper is intended to provide a detailed account of the development and implementation of modern pipe fabrication at NASSCO. Included is a complete discussion of the facility modernization from initial economic feasibility studies through detailed facility design. The group technology-oriented manufacturing control philosophy is described with discussion including classification, labor standard development, detailed shop planning/scheduling, cost collection and performance measurement. Human factors are addressed and projected productivity improvements discussed. Finally, several facility and technology enhancements are identified as appropriate steps to further improvements in the manufacturing operation.

2.0 FUNDAMENTAL CONCEPTS OF MODERN PIPE FABRICATION

In order to provide a complete discussion of modern pipe fabrication at NASSCO it is necessary to identify several concepts that reflect efficient manufacturing of pipe pieces to support modern ship construction methodology. These concepts formed the basic objectives of the pipe fabrication modernization project at NASSCO and are described below:

Objective 1: Dictate the design of the spools to conform to facility constraints and optimum fabrication techniques.

A pipe spool is an assembly of pipe, flanges and fittings that is defined as part of a particular piping system. Pipe spools are assembled in the pipe shop in order to minimize the amount of pipe fitting and welding required during subsequent construction stages (on-unit, on-block, on-board). This objective addresses the need for pipe spools to be designed for producibility at the lowest practical cost. In order to satisfy this need, a great deal of production-oriented knowledge must be reflected in the design of the pipe spool. Included in this knowledge is an understanding of machine and facility constraints, fabrication methods and manufacturing sequences.

While this objective is not addressed in detail here, it should be noted that several efforts are currently underway at NASSCO to provide for effective transfer of current production knowledge into the design process. The efforts include a production-oriented design manual developed jointly

between Engineering and Pipe Shop personnel, seminars in pipe fabrication for those directly involved in spool design and continuous liaison interaction to resolve problems encountered day to day.

Objective 2: Gain organizational control over the total manufacturing process.

In the case of pipe fabrication to support ship construction, manufacturing is not complete until all operations, including cleaning and coating of the pipe spool, are completed. Additionally, pipe spools must be grouped or "packaged" to support the work breakdown structure of subsequent stages.

Effective manufacturing control and thus lower total cost for the shipyard is achieved when all manufacturing operations are responsible to the organization responsible for manufacturing. This may seem obvious but is not always easy to implement given existing facilities and organizational structures. Additionally, the operations should be adjacent to one another to gain the benefits of reduced material handling.

Objective 3: Increase the level of fabrication technology in the pipe shop.

Advances in machine technology have a positive effect on productivity with respect to operation

process times. Automated material handling technology as well as rational plant layout reduces non-process time and also has a positive effect on productivity.

Objective 4: Simplify and streamline product flow and process sequence.

From an industrial engineering perspective, the simplification of the manufacturing process through effective plant layout, operation resequencing and the definition of process flow lanes results in an efficient, streamlined product flow. This translates into reduced operating costs, better control of the work flow and a framework in which continuing improvements can be made.

Objective 5: Develop consistent methods to plan, schedule, route, collect cost and compute performance with respect to the manufacturing processes involved.

An integrated manufacturing control philosophy incorporating group technology techniques for controlling the work flow through the shop is necessary to effectively manage the the manufacturing operation. The philosophy must reflect current facilities and capabilities and provide for explicit means to project future work, accomplish scheduled work, record finished work and compute the necessary productivity parameters used in the management of the shop.

3.0 FACILITY MODERNIZATION

Economic Analysis / Justification

The design of a facility to support modern pipe fabrication was accomplished in three basic stages. Stage One consisted of an analysis of the economic feasibility of the facility modernization based on projected throughput and three modernization alternatives. The results of this analysis led to a subsequent justification analysis addressing the most favorable of the alternatives. Stage Two consisted of a survey of selected domestic and foreign pipe fabrication operations. Stage Three was the development of the detailed design of the facility including detailed shop layout, equipment specification and construction planning.

The feasibility study addressed three facility modernization alternatives representing varying levels of productivity improvement at varying levels of investment. The first alternative was an upgrade of the existing pipe shop consisting of a rearrangement of equipment to support improved material flow and selected equipment acquisitions to upgrade the current manufacturing technology in the shop. Since the size of the existing shop was fixed (approximately 28000 square feet), this alternative dictated that the cleaning, painting and packaging (palletizing) of pipe spools would remain physically and organizationally separated from the prior fabrication operations.

The second alternative involved the upgrade of the existing pipe shop, the acquisition of an adjacent building previously used for foundry operations and the dedication of all the area surrounding the pipe shop and foundry to pipe fabrication. This alternative represented an increase of approximately 25000 square feet and allowed for the centralization of all pipe spool manufacturing operations both physically and organizationally. The following operations were included in this design:

- o in-process storage, pipe and fittings
- o external abrasive cleaning of pipe
- o cutting to length of pipe
- o cold-bending of pipe
- o fitting
- o welding
- o chemical cleaning
- o galvanizing
- o painting
- o palletizing (packaging)

Additionally, equipment was identified that would upgrade current technology in the shop.

The third alternative consisted of the construction of a new pipe fabrication facility based on a shop layout designed to optimize product flow by strategic location of work centers and installation of state-of-the-art material handling systems. New equipment was identified as part of this alternative.

Based on the results of the feasibility study, alternative number two was determined to be the most cost-effective of the three. A detailed cost/benefit analysis of this alternative was carried out and in the spring of 1984 the funding for the modernization of the pipe fabrication facilities at NASSCO based on alternative number two was approved.

Industry Survey

An industry survey was conducted during the first quarter of 1984 to assess various pipe fabrication operations in terms of shop layout, product flow, material handling, current equipment technology, manufacturing control procedures and the product mix normally processed through the individual shops. Four domestic and two foreign pipe fabrication operations were visited. They were:

- o Pipe shop, Avondale Shipyards, Inc., New Orleans, Louisiana
- o International Piping Systems, Ltd., Port Allen, Louisiana
- o Pipe Shop, Ingalls Shipbuilding, Litton Industries, Pascagoula, Mississippi
- o Texas Pipe Bending Company, Houston, Texas
- o Pipe fabrication works, Aioi Shipyard, IHI Company, Ltd., Aioi, Japan
- o Pipe shop, Kure Shipyard, IHI Company, Ltd., Kure, Japan

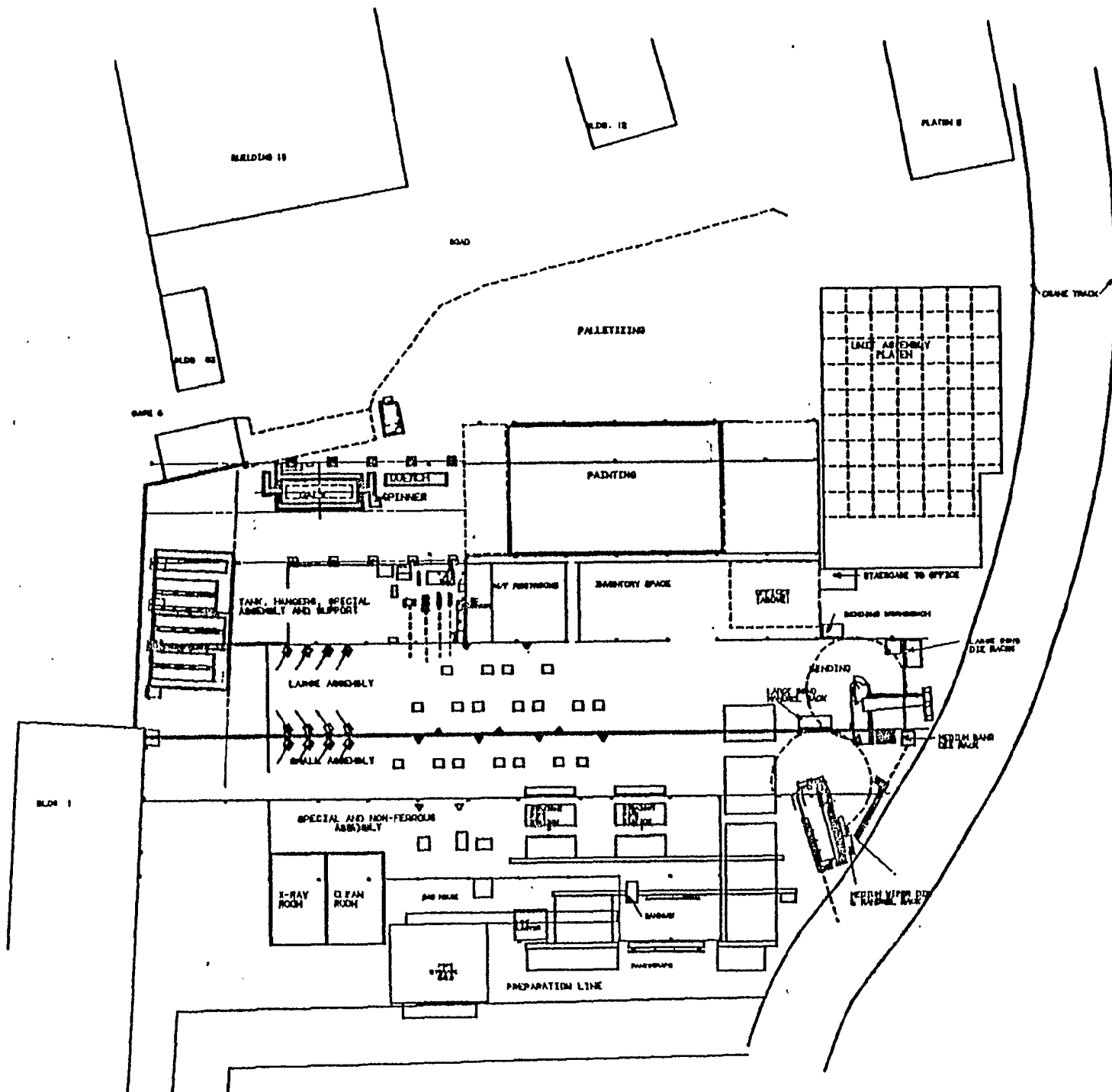
A rigorous analysis of these operations helped to formulate the design criteria used to develop the detailed shop layout and equipment specifications of the modernization. Also instrumental in the conceptual development of both the facility and the philosophy were several reports published by the National Shipbuilding Research Program. (1,2)

Detail Facility Design

The pipe fabrication facility to support modern ship construction methodology at NASSCO encompasses an area of approximately 53000 square feet. In the facility, the manufacturing of pipe spools proceeds from in-process raw material storage of pipe and fittings to packaging (palletization) of completed, painted pipe spools. The facility is divided into five functional areas, each area corresponding to one of the five major manufacturing operations defined for a pipe spool. A definition of the area utilization is given in Table I and a layout of the facility is given in Figure I.

TABLE I
Area Utilization

Area	Square Feet	Percent
Preparation	6500	12 %
Bending	5700	11 %
Assembly	15000	28 %
Treatment	16000	30 %
Palletize	7000	13 %
Support	2800	6 %



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FIGURE I
Pipe Shop Layout

Preparation Area

The preparation area consists of equipment and machinery used to store, clean, cut and convey raw pipe stock in support of subsequent bending, assembly or treatment operations. The configuration of the raw material is well suited for automated material handling applications and is exploited in the preparation area. A steel structure capable of storing over twelve thousand feet of raw pipe stock from 2"-12" in diameter and 20-24 feet in length in a series of horizontal shelves allows for the rapid withdrawal of pipe by material, schedule and diameter. Pipe withdrawn from the storage structure (silo) is then transported via axial conveyor to a shotblasting machine where rust, mill scale and preservative are mechanically removed from the exterior of ferrous pipe. After processing through the shotblast machine, pipe is transported via axial conveyor to the cutting center where the raw pipe stock is cut to the design lengths specified for each pipe spool. The cutting is performed on a vertical bandsaw or contour cutting machine. After cutting, the "pre-cut" pipe pieces are then axially and laterally transported to three buffer tables where they are staged for bending or assembly. The entire material handling system is designed for automatic operation on pipes up to 12" in diameter. For larger diameter pipe, semi-automatic processing through the preparation area is possible. The preparation area is in the final phase of installation and is scheduled for production early in 1986.

Pre-cutting pipe prior to bending or assembly represents a major change in the traditional fabrication methodology employed in the pipe shop. The implementation of pre-cutting as the first manufacturing process in the shop is anticipated to yield substantial productivity improvement in the overall pipe spool manufacturing operation.

Bending Area

Adjacent to and downstream of the preparation area is the bending area where pipe requiring bending is processed on one of three sizes of rotary-type hydraulic cold bending machines. The machines are capable of bending pipe up to 12" in diameter and are grouped in the following way:

- o large bending - 6"-12"
- o medium bending - 2-1/2"-4"
- o small bending - up to 2-1/2".

Pre-cut pipe pieces requiring bending are staged in the bending area on buffer tables connected to the preparation line. To support the manual loading and unloading of pipe onto and off of the bending machines, the existing overhead bridge cranes of the old pipe shop were utilized. Crane rail extension was necessary to provide complete support for medium-sized bending. After bending, the overhead bridge cranes transport the pipe pieces into the assembly area where they are staged with the necessary material needed to complete the pipe spool.

Assembly Area

Occupying the old pipe shop building and arranged in four basic process lanes is the assembly area of the pipe shop. In the assembly area raw pipe stock, flanges and fittings are fitted and welded to form an assembly of components referred to as a pipe spool. The spool is fabricated according to design information provided on supplementary instruction sheets or "spool sheets".

At the beginning of the assembly area is a material staging zone where the pre-cut and/or bent pipe pieces are kitted with the necessary fittings and/or flanges that correspond to a particular pipe spool. From this zone, material is delivered to individual work benches at the discretion of the assembly area supervision.

The process lanes defined in the assembly area are as follows:

- o straight pipe spool assembly
- o large complex pipe spool assembly
- o small complex pipe spool assembly
- o special and support assembly

The straight pipe spool assembly lane is integrated with the material handling system of the preparation line. The lane is intended to process straight pieces of pipe with sleeves, couplings or flanges on one or both ends in a semi-automatic manner. All material transport will be by way of axial conveyors and inclined lateral transfer tables. Fitting and welding stations are designed such that pipe is deliv-

ered to them on one of the inclined transfer tables. The fitting station allows for leveled, jig-supported fitting of sleeves, couplings and flanges on one or both ends of straight pipe while the welding station, supported by powered rollers and an overhead trolley carrying the necessary welding equipment, allows for semi-automatic welding of several welding processes. The straight pipe processing line will come into production with the completion of the preparation area early in 1986.

The design of the straight pipe lane followed a prototype approach where existing equipment and components were modified to suit defined processing requirements. This prototype will be used to generate the technical specifications for a more sophisticated semi-automatic or automatic processing station to be incorporated into the straight pipe lane at a later date.

The complex pipe spool assembly lanes support the manual fitting and welding operations that are necessary on two and three dimensional pipe spools. Standard fitting benches are installed in each lane with a material delivery aisle down the center of the large complex lane and down the side of the small complex lane. The large complex pipe spool lane corresponds to the large bay of the assembly area and is intended to process pipe spools 6" in diameter and above. The small complex pipe spool lane corresponds to the small bay of the assembly area and is intended to process pipe spools 4" in diameter and below.

After fitting at one of the fabrication work benches in the assembly area, the pipe spool is transported to the "weld-out" zone of the assembly area where it is production welded on positioning machines. It should be noted that two welding stations are installed in the fitting area to support more efficient welding of straight sections of complex spools. The stations are referred to as "roll-out" stations.

After the spool has been welded, it is staged for processing through the treatment area.

Treatment Area

The treatment area contains facilities for chemical cleaning, hot-dip galvanizing and painting pipe spools. Installed in this area are eight tanks containing chemical cleaning solutions, a gas-fired molten zinc kettle and an enclosed painting cabin. Fabricated and welded pipe spools are processed through the area by a system of overhead bridge and gantry cranes and by wheeled painting racks used in the paint cabin.

The constraints imposed by existing structures and the overall configuration of the treatment area dictated the need for a unique material handling system design. The two overhead bridge crane rails for the large and small assembly bays were extended to span the entire treatment staging area. The cranes serve as the primary method of transport for spools completed in the assembly area. Operating at approximately right angles to and just below the rails of the overhead

bridge cranes is a half-gantry crane with a column-supported rail against the side opposite the assembly area and a ground-level rail adjacent to the assembly area. The half-gantry is used to process batches of pipe spools requiring similar treatment processes through the chemical cleaning tanks. After chemical cleaning, spools are staged in one of two adjacent bays depending on the type of coating required. The bays run at approximately right angles to the half-gantry rails and are supported by side-by-side bridge cranes which run on rails just above the half-gantry crane. In the first bay, pipe spools requiring hot-dip galvanizing are processed through a galvanizing kettle and water quench tank and then staged for painting or palletizing. The second bay is used as a staging area for spools requiring painting only.

Chemical cleaning is performed on ferrous piping to provide the necessary surface preparation for galvanizing or painting. in the past, only pipes requiring galvanizing were processed through the cleaning tanks. Pipes requiring painting were transported to another area in the shipyard for manual shotblasting to establish the correct surface preparation. Chemical cleaning of all ferrous piping prior to galvanizing or painting is a significant improvement in the processing of completed pipe spools and is anticipated to yield substantial improvement in the productivity of the manufacturing operation.

To provide the ability to paint pipe spools at the pipe shop, a 88'-0 by 52'-0 ventilated paint cabin was installed. The cabin is divided into four quadrants designed to provide for painting and drying of several different paint systems simultaneously. There are two painting areas and two drying areas, each of which is supported by a separate filtering and ventilation system. Material handling in the paint cabin is accomplished by push carts loaded with racks designed for pipe spool painting.

Palletizing Area

Completed pipe spools are packaged for subsequent installation in the palletizing area. The area is divided into 20 marked locations where packages of pipe spools are maintained. The pipe spools are stored in steel tubs or "pallets" approximately 12 feet long by 6 feet wide by 2 feet high. The configuration of the pallets allows for stacking up to 4 high in each marked location making the total number of possible packages to be maintained in this area 80.

Recent operations have indicated that this area is not sufficient to adequately handle both the kitting and storage operations. High throughput requirements of the pipe shop to meet production schedules has caused severe overcrowding of the area and consequently reduced operating efficiency. Another area in the shipyard located approximately 100 yards away is currently being used to kit and store completed packages until they are needed for installation.

Unit Assembly Area

In support of the stage of construction philosophy utilized in modern ship construction technology, a unit assembly platen was installed as part of the pipe fabrication facility modernization project. The platen, fabricated from surplus steel hatch covers removed from a recent ship conversion contract, is approximately 8000 square feet in area and is utilized for the construction of outfitting units and pipe racks. To support this type of construction, the unit assembly area is fitted with several jib cranes, a complete list of the services required for fitting, burning and welding and an inventory area used to supply small parts such as nuts, bolts, pipe hangers and gaskets.

Miscellaneous Facility Enhancements

While the majority of the facility enhancement effort was directed at the five functional areas previously identified, several other improvements were also carried out. They were the following:

Installation of an inventory space for in-process material. The inventory space is located adjacent to the assembly staging area to facilitate kitting of material with pre-cut pipe pieces processed on the automated pipe processing line. Also located in the inventory space is a tool room and weld rod storage area.

Installation of restroom facilities including lockers and shower facilities. The restrooms were installed to replace existing restroom facilities and represent a significant upgrade in the habitability of the pipe shop.

Installation of a second-floor office space. The office space was installed to provide a centralized location for the administration and management of the five functional areas in the shop. Through this office, the manufacturing of pipe spools from initial material withdrawal from the yard warehouse to delivery of fabricated, coated pipe spools packaged by installation requirements to the subsequent stages of construction is coordinated. All supervisory and clerical personnel associated with the manufacture of pipe spools are located in this office.

4.0 MANUFACTURING CONTROL PHILOSOPHY

Introduction

Much emphasis has been placed on the installation of state-of-the-art equipment and facilities to improve the competitive position of shipyards and specifically shipyard outfitting shops. While modern equipment and material-handling techniques do increase productivity, substantial improvement can also be achieved through the effective application of manufacturing control methodologies, especially those that employ principles of group technology. This is particularly true in the case of pipe shops where group technology principles identifying the "sameness" of parts can be readily applied to the fabrication of pipe pieces.

Concurrent with the design and installation of the new pipe fabrication facilities at NASSCO was the design and development of a group technology-oriented manufacturing philosophy. The philosophy identified integrated techniques for scheduling and routing work through the shop, projecting manpower requirements, collecting fabrication costs and computing performance parameters in a way that could be meaningfully applied to the management of the manufacturing effort. This section describes that philosophy by discussing the methods currently being implemented in the pipe shop at NASSCO. Before going into the details of the implementation, however, it is necessary to present a brief discussion of group technology manufacturing and how it relates to pipe fabrication.

Group Technology With Respect to Pipe Fabrication

The origin of group technology (GT) is somewhat obscure but researchers on the subject generally agree that S. P. Mitrofanov of the USSR was the originator of the technique. It is also agreed that Mitrofanov's developments were based on work originally done by A. P. Sokolovski, also of the USSR. In the 1930s Sokolovski suggested that, in general, standardized processes and manufacturing techniques should be used on parts of similar configuration and features. A translation of a more applicable definition is provided by Mitrofanov:

GT is a technique for manufacturing small to medium sized batches of parts of similar process, of somewhat dissimilar materials, geometry and size, which are produced in a committed small cell of machines which have been grouped together physically, specifically tooled, and scheduled as a unit. (3)

Using this definition as a basis, group technology manufacturing with respect to pipe fabrication can be defined as the identification of the "sameness" or commonality of parts, specifically pipe spools, by virtue of those attributes which define the specific manufacturing processes required; and subsequent grouping or classification of those like parts to maximize the efficiency of the work centers producing them. It is possible, under this definition, for work to flow in a line or series fashion, utilizing the same equip-

ment or machinery as in the preparation or treatment areas, or for work to be accomplished in a parallel, process lane fashion, as in the bending or assembly areas.

Classification of Pipe Pieces

A necessary element for the implementation of group technology manufacturing techniques is the development of a classification system by which to accurately categorize the scope of work to be processed. The following definition is applicable:

A technique to organize. specific data relating to the relevant component element(s) of a business or institution in a logical and systematical hierarchy, whereby like things are brought together by virtue of their similarities, and then separated by their essential differences. (4)

To expand on this, the following principles are defined:

- o All Embracing - A classification must embrace all items and be able to accept necessary new items into the defined population of items.
- o Mutually Exclusive - A classification must bring like items together while excluding unlike items, using clearly defined parameters. That is, there must be one place and one place only for any one item.

- o **Based on Permanent Characteristics** - A classification must be based on visible attributes or easily confirmed permanent or unchanging characteristics. Fortuitous, ambiguous and non-permanent characteristics must not be used.
- o **From User's Viewpoint** - A classification should be developed from a single point of view, that of the user and not the classifier. (5)

A classification system for the manufacturing of pipe spools at NASSCO was developed using the above principles as guidelines. The system is based on five attributes of the design and manufacture of a pipe spool. The attributes are:

- o material
- o size (diameter)
- o configuration
- o assembly
- o treatment

The size attribute is imbedded into the configuration and assembly attribute in order to simplify the coding of the classification system. The following is an explanation of each of the four "explicit" attributes.

The material attribute identifies from what type of material the spool is manufactured. This attribute is design or specification driven in that the material type will be determined by the shipboard piping system the pipe

spool will ultimately become a part of. The purpose of this attribute in the classification system is to define what type of processing the spool will undergo in the shop (i.e. flame versus mechanical cutting, 3-D versus 5-D cold bending, welding versus brazing). This information is utilized in the determination of shop routing, scheduling and loading.

The configuration attribute identifies cold bending requirements of a pipe spool. Cold bending in lieu of fittings is cost-effective from a fabrication standpoint. Where possible, designers are instructed to use bends as a means to change the direction of a piping system run. In the shop, this means' that the pipe spool must be scheduled and routed through one of three rotary-type hydraulic bending machines located in the bending area. These machines bend pipe from 1" to 12" in diameter. The configuration attribute defines whether bending is required and if so, which of the machines will be used.

The assembly attribute identifies the type of assembly required for the spool and also identifies the process lane in the shop where the spool will be assembled. There are two basic types of assembly: straight and complex. Straight assembly is defined as fitting and welding of flanges, sleeves, couplings and selected fittings on one or both ends of raw pipe stock in a semi-automated manner. Complex assembly is defined as any assembly requiring set-up of the spool on a workbench and lack-stands. Assembly is further broken down into large and small based on diameter where small is 1"

to 4" and large is 6" to 12". Pipe spools over 12" in diameter are regarded as special assembly. Other spools requiring unique assembly are also classified as special using this attribute. The assembly attribute is not design or specification driven but is used solely for production control in the shop.

The treatment attribute describes the treatment processes required for the spool after fabrication. These processes are dictated by the shipboard piping system and ship zone where the spool will ultimately be installed. In this respect, the treatment attribute is design-driven. The processes identified under this attribute include chemical cleaning, galvanizing and painting.' The attribute identifies the various combinations of these processes.

Coding System

The classification system is supported by a four digit numerical coding system which defines all possible values of the four pipe spool attributes. The four digit code, commonly referred to as the family number, defines ninety-three possible pipe spool families. The following is a listing of possible attribute values. Figure II summarizes this information.

Material Attribute

- 1 Ferrous - ASTM A-106, ASTM A-53 or any other material having characteristics that allow

it to be processed through the shop in the same manner as the above specifications.

- 2 Non-Ferrous** - ASTM B-88 Copper Type-K, ASTM B-466, B-467 (CuNi 90-10) Alloy 706 or any other material having characteristics that allow it to be processed through the shop in the same manner as the above specifications.
- 3 Other** - special materials not classified under 1 or 2 above. Examples include fabricated hoses and fiberglass reinforced plastic pipe.

Configuration Attribute

- 0 No Bending - any pipe spool not requiring bending.
- 1 Large Bending - pipe spools 6" to 12" requiring bending.
- 2 Medium Bending - pipe spools 2-1/2" to 4" requiring bending.
- 3 Small Bending - pipe spools 2" and below requiring bending.

Assembly Attribute

- 0 No Assembly - any pipe spool 1" to 12" not requiring assembly (defined here to be fitting, welding, brazing and/or bolting).

- 1 Large Straight - pipe spools 6" to 12" in diameter with a flange or coupling on one or both ends.
- 2 Small Straight - pipe spools 1" to 4" in diameter with a flange or coupling on one or both ends.
- 3 Large Complex - pipe spools 6" to 12" in diameter requiring manual assembly of fittings, flanges, sleeves, saddles, etc.
- 4 Small Complex - pipe spools 1" to 4" in diameter requiring manual assembly of fittings, flanges, sleeves, saddles, etc.
- 5 Special Assembly - pipe spools not falling into any of the above assembly categories due to size (greater than 12"), special assembly processes (miter cuts, *threaded ends 2-1/2" and above), special assembly sequences (weld after galvanize), testing requirements or exotic materials.

Treatment Attribute

- 0 No Treatment - pipe spools not requiring treatment.
- 1 Clean/Paint - pipe spools requiring chemical cleaning and painting at the pipe shop.
- 2 Clean/Galvanize/Paint - pipe spools requiring chemical cleaning, galvanizing and painting at the pipe shop.

Shop Work Center Definition / Duration Assessment

The fundamental concept of the pipe fabrication manufacturing control philosophy is that the classification system described above can be used to define the routing, scheduling, duration and work content information for any spool by associating it with one of the ninety-three families described above. In this way, detailed production control information can be generated at the spool level much quicker, easier and according to more standardized rationale than if the same information had been generated for each individual spool.

Shop routing for spools is accomplished by associating each spool to a sequence of work centers in the shop based on its family number. There are five work centers defined for the pipe shop, each corresponding to one of the five functional areas in the shop. The work centers are given in Table II.

TABLE II

Shop Work Centers	
Number	Work Center
100	Preparation
200	Bending
300	Assembly
400	Treatment
500	Palletize

Every spool manufactured in the pipe shop can be routed through a series of these work centers. The routing is always sequential with routing through preparation and palletizing required for all spools. This generates the eight possible routings shown in Figure III.

```

100 -> 200 -> 300 -> 400 -> 500
100 -> 200 -> 300 ->      -> 500
100 -> 200 ->      -> 400 -> 500
100 -> 200 ->      ->      -> 500
100 ->      -> 300 -> 400 -> 500
100 ->      -> 300 ->      -> 500
100 ->      ->      -> 400 -> 500
100 ->      ->      ->      -> 500

```

FIGURE III

Work Center Sequence

The routing is further broken down to sub-centers for work centers 200, 300 and 400, each sub-center corresponding to the possible values for the configuration, assembly and treatment attributes of the family number. Table III illustrates.

TABLE III

Work Centers and Sub-Centers

Work Center 200: Bending

sub-center: 201 - Large Bender
sub-center: 202 - Medium Bender
sub-center: 203 - Small Bender

Work Center 300: Assembly

sub-center: 301 - Large Straight Assembly
sub-center: 302 - Small Straight Assembly
sub-center: 303 - Large Complex Assembly
sub-center: 304 - Small Complex Assembly
sub-center: 305 - Special Assembly

Work Center 400: Treatment

sub-center: 401 - Chemical Cleaning/Paint
sub-center: 402 - Chemical Cleaning/Galvanize/Paint
sub-center: 403 - Chemical Cleaning/Galvanize
sub-center: 404 - Paint

Using this rationale a spool having a family number of 1043 would have the following routing:

100 -> 304 -> 403 -> 500

Once the routing for a spool is established, duration estimates by work center or sub-center are necessary to develop detailed work center schedules at the spool level. Without going into an exhaustive explanation of how these duration estimates were generated, it is sufficient to say that estimates were developed through a systematic and rational analysis with attention given to types of work performed, processing times involved, material handling aspects and in-process storage considerations. These estimates are applied to the pipe spool families at a particular center or sub center. The total estimated manufacturing duration for a family is the sum of the individual center or sub-center duration estimates based on the routing for that particular family. Therefore, if the family above had the following duration estimates:

100 Preparation	1 day
304 Small Complex Assembly	3 days
403 Chemical Cleaning/Galvanizing	4 days
500 Palletizing	2 days

the total duration estimate for the spool that would be used in scheduling the spool in the shop would be 10 days.

Labor Standard Development

Recent studies have indicated that the application of labor standards to planning and scheduling work performed in shipyard outfitting shops can be effective in increasing shop productivity. A MARAD-funded scheduling standards pilot project conducted at Peterson Builders, Inc., Sturgeon Bay, Wisconsin, revealed that work measurement techniques applied to pipe fabrication planning and scheduling were instrumental in reducing pipe fabrication costs. (6)

Early in the development of the classification system for pipe spools at NASSCO it was perceived that work content estimations could be incorporated into the system to provide information on the manloading required in the shop to support defined schedules. Using the industry research at Peterson as a basis NASSCO initiated a project to collect simplified work measurement data in the pipe shop. The data was subsequently reduced to form a preliminary labor standards database which was further reduced to yield work content estimations for spools at work centers and sub-centers in the shop based on their family classification.

It is necessary to clarify the purpose of the pipe fabrication labor standards database mentioned above and to provide a discussion on methods used in its development. Through this discussion it will be clear to the reader that

the work measurement data represents an initial approach to the subject of manloading and manpower forecasting at a shop level and by no means a collection of "formally engineered" labor standards.

The purpose of the labor standards database is to serve as an initial, first-cut approximation of processing times in the shop in order to estimate manloading in the shop for a given shop schedule. To support these efforts, the level of accuracy required can be achieved through an "informal" approach to work measurement data analysis where the accuracy of time standards is not critical. (7)

Work measurement data was collected in the pipe shop over a two month study period. Actual times for specifically defined operations were collected by the individual workers performing those operations and subsequently organized with respect to material, diameter and operation (or process). Charged time for all shop work was also recorded during the study period in order to estimate aggregate shop process and non-process time. Several assumptions were made in this simplified approach to work measurement sampling:

- o Individual workers would record their individual process times themselves.
- o Variation of measurements taken by the individual workers, while not precise on an individual basis, will form normal distributions around some average value where the range of reasonable measurements can be approximated

- o The average value determined for each process recorded in the study can be used to approximate the required effort (expressed in units of time) for that process for planning and scheduling work in the pipe shop.
- o Total time charged in the pipe shop is made up of actual process time (time spent doing a recorded study process) and non-process time (personal fatigue and delay time, non-recorded process time, management caused delays).
- o The aggregate non-process time in the shop is the weighted summation of all the individual non-process times associated with each shop operation and can be determined by the difference between the total time charged in the shop and the actual process time recorded in the shop, provided that actual process time is recorded for all work in the shop.
- o For shop scheduling purposes, the individual non-process times associated with each shop operation can be approximated by the aggregate shop non-process time expressed as a fraction of the total time.

As indicated previously and further illustrated by the assumptions outlined above, the intent of this effort was not to produce a highly-refined labor standards database for pipe fabrication but to generate estimates of work content that were accurate enough to use in the planning and scheduling of work through the shop.

The work measurement data was reduced and re-organized for quantitative and qualitative analysis which subsequently yielded a set of average actual process times by diameter and material. This set of average actual times form the basis of the preliminary labor standards database for pipe fabrication at NASSCO. In order to apply the information contained in this database to the specific families defined by the classification system, the individual process times were grouped into combinations, each combination representing the planning time required for a particular pipe spool family at a particular work center or sub-center in the shop. The rationale surrounding the combination of the process times into planning times by family was similar to the analysis carried out in developing duration estimates for pipe spool families. The result was a manhour matrix where entries represent the estimated work content for a particular pipe spool family at a particular work center in the shop. Therefore, using the previous example, family 1043 may have the following work content estimate:

100 Preparation	0.2 Hour
304 Small Complex Assembly	3.3 Hour
403 Chemical Cleaning/Galvanizing	0.6 Hour
500 Palletizing	0.2 Hour

which would indicate a contribution of 4.3 hours to the scheduled shop load for spools with a family classification of 1043.

Detail Shop Planning / Scheduling

The association of routing, duration assessments and work content assessments to pipe spool families allows for rapid definition of the same for individual pipe spools. This level of planning and scheduling detail is significantly greater than that which had existed in the past. Earlier fabrication control was accomplished at a higher level where all spools, regardless of sometimes significant differences in complexity and fabrication requirements were treated equally and scheduled identically. This lack of visibility impeded the resolution of production control problems in the shop. The manufacturing control philosophy currently being implemented, however, supplies visibility to the machine level, thus establishing the basis for bringing the manufacturing operation into statistical control.

This is not without cost, however. The more detailed approach requires a significant increase in administrative effort to maintain a more detailed system. To partially satisfy this requirement, automated processing on a shop-based microcomputer was implemented which automatically generates schedules for spools by individual work centers and sub-centers in the shop. The flexibility of the shop-based processing system allows for information to be generated in a variety of formats to support the specific information requirements of the supervision in the shop.

Currently, the implementation of detailed shop planning and scheduling based on the principles established in the classification system and utilizing the shop-based micro-computer is underway.

Cost Collection / Performance Measurement

In any manufacturing operation the collection of labor costs associated with the production of parts is necessary in order to pay employees, report performance to budget and compute productivity. The latter requirement is the subject of this section.

Labor charges in the pipe shop are collected by functional area. This facilitates the simple computation of productivity parameters by work center or sub-center by recording center throughput, expressed in units of standard hours, spools, cuts, bends, etc., and dividing the value by

the number of hours charged to each center. In this way, detailed monitoring of productivity down to the machine level can be accomplished.

Collecting costs by functional area represents a significant departure from traditional collection techniques. In the past, labor was charged using a system-oriented work-breakdown structure where charges for all processes in the shop were cumulated thus preventing visibility for individual process costs. The current method of collecting costs defines cost centers or sub-centers which correspond to the work centers and sub-centers previously defined. Using this breakdown, one only needs to know in what area an individual is working in the shop to determine the correct charge number. This greatly improves the accuracy of labor charging in the shop while providing the visibility required for a self-improving manufacturing methodology.

Currently, charges are being collected at the work center level in the shop. Table IV identifies the cost centers and sub-centers currently defined.

T A B L E I V

Cost Centers and Sub-Centers

Cost Center 10: Preparation

Cost Center 20: Bending

sub-center: 21 - Large Bender

sub-center: 22 - Medium Bender

sub-center: 23 - Small Bender

Cost Center 30: Assembly

sub-center: 31 - Large Straight Assembly

sub-center: 32 - Small Straight Assembly

sub-center: 33 - Large Complex Assembly

sub-center: 34 - Small Complex Assembly

sub-center: 35 - Special Assembly

sub-center: 36 - Tank, Hanger and Support Assembly

Cost Center 40: Treatment

sub-center: 41 - Chemical Cleaning

sub-center: 42 - Galvanizing

sub-center: 43 - Painting

Cost Center 50: Materials

sub-center: 51 - Shop

sub-center: 52 - Shop

sub-center: 53 - Storage (Palletizing)

5.0 CONCLUSIONS

Summary

The pipe fabrication modernization project initiated at NASSCO in the fall of 1983 identified five major objectives as key elements to modern pipe fabrication:

- o Dictate the design of the spools to conform to facility constraints and optimum fabrication techniques.
- o Gain organizational control over the total manufacturing process.
- o Increase the level of fabrication technology in the pipe shop.'
- o Simplify and streamline product flow and process sequence.
- o Develop consistent methods to plan, schedule, route, collect cost and compute performance with respect to the manufacturing processes involved.

With respect to the first objective, continuing efforts are being directed into the Engineering/Production interface to insure spool design that supports efficient spool manufacturing. Included in this interface is a continuous transfer of fabrication methodology so that designers can develop design "principles" that support the production effort rather than "rules" which must be followed without necessarily understanding the reasons why.

With the centralization of the manufacturing operations into one shop, organizational control was also centralized.. Currently, all manufacturing operations from the in-process

storage of pipe and fittings to the palletization of painted pipe spools are the responsibility of the individual responsible for pipe spool manufacturing.

The facility enhancements associated with the modernization project will complete early in 1986. Outstanding items are the installation of the preparation line and installation of the straight pipe processing station. The completion of these items, as well as the enhancements completed thus far represent a significant increase in the level of fabrication technology in the shop and a substantial improvement in the streamlining of the work flow in the shop.

The group technology-oriented manufacturing control philosophy is partially implemented with full implementation to follow the completion of the preparation line. This philosophy integrates all elements of manufacturing control by utilizing group technology principles with respect to pipe fabrication.

Assessment of Productivity Improvement

The lack of significant labor returns to date as well as the incomplete status of the overall project prevent quantitative discussion of the productivity improvement currently being experienced in the shop. It appears, however, that throughput capacity has increased substantially. Analysis of throughput data for the past several years indicates sustained throughput values much higher than traditional values at the same unit cost (hour/spool).

It is the opinion of the author that with effective management in the shop and complete implementation of the methods discussed in this report, productivity in the manufacturing of pipe spools can be improved by 100 percent over traditional values. In other words, the cost per spool considering the total manufacturing effort will be cut in half.

Anticipated Programs

The modernization program for pipe fabrication described in this report represents the initial phase of a continuing effort to provide state-of-the-art facilities and manufacturing technologies in the pipe shop at NASSCO. Long-range planning has identified programs in several areas which also support this goal. Three of these programs are identified below.

The application of statistical process control (SPC) techniques has been shown to be effective in manufacturing environments for the control of quality and subsequent improvement in manufacturing efficiency. The implementation of SPC techniques in the pipe shop at NASSCO is supported by the simplification and streamlining of the product flow through the shop. SPC is considered to be a necessary element in continuing to improve the productivity in the pipe shop.

The manufacturing sequence currently defined in the pipe shop is a significant improvement over traditional operations. A further improvement recognized as necessary in the optimization of product flow through the shop, however, is the implementation of straight pipe fabrication prior to bending and assembly. This operation would minimize fabrication costs by utilizing highly efficient straight pipe processing wherever possible. The assembly bays would be utilized for final assembly of straight or bent pipe pieces into pipe spools. Manual fitting and welding would be minimized.

The design and creation of the supplementary instruction sheets (spool sheets) used to provide manufacturing information to the pipe shop is currently a manual process. Three-dimensional CAD (Computer-Aided Design) systems are capable of automatically generating material lists, classification data and manufacturing data for piping systems. The installation and implementation of CAD facilities in Engineering for automatic generation of pipe spool manufacturing data supports the modernization effort with respect to pipe fabrication at NASSCO.

Human Factors

It must be recognized that the success or failure of any project, whether it involves the installation of new facilities or implementation of new methodologies, is dependent on how well the personnel affected assimilate to

the changes introduced. This is particularly true when responsibilities are expanded or areas of concentration redefined.

Several steps can be taken to insure adoption of new methods and optimum utilization of new facilities. The involvement of affected personnel early in the design process will not only create a sense of ownership but will many times reveal deficiencies in the design that would have later resulted in operational problems. Developing an understanding in the affected personnel of the principles and key Objectives of the change eliminates automatic response to problems and replaces it with systematic solutions. Continuous' training in terminology, procedure, methods and policies deters confusion and uncertainty associated with change.

To reiterate, only with the support and enthusiasm of the individuals who will be responsible for the execution of the changes proposed will the efficiencies estimated in design be approximated in the "real" world.

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